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RESEARCH PAPER

Impact of *Dysphania ambrosioides* L. extract on the selected quality characteristics of orange-acerola sorbets

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Abstract

Sorbet is a low-calorie, refreshing dessert that has been studied through the addition of natural ingredients to improve its health benefits. In this study, different concentrations of aqueous extract from *Dysphania ambrosioides* L. (DA) leaves were incorporated into an orange-acerola sorbet to assess its impact on selected quality parameters. Adding 3.3% DA extract increased the pH from 2.42 to 2.49 and decreased the acidity from 0.57 to 0.55%. Sorbets with higher extract concentrations appeared lighter with a slightly yellowish tone, while parameters such as overrun, melting rate, and vitamin C content remained unaffected. The total phenolic content (TPC) increased by 3.3%, from 48.52 to 55.48 mg/100 g, potentially due to specific compounds in the plant, such as o-cymene. The addition of 3.3% extract was noticeable only in taste, yet the sorbet maintained scores above 6 and showed good purchase intent. In conclusion, sorbets with the highest concentration of *D. ambrosioides* extract provided a higher phenolic content without negatively affecting quality parameters, while still being well accepted by consumers.

Keywords

Chenopodium ambrosioides, phenolic compounds, sensory acceptance, sorbets, technological parameters, volatile compounds

Introduction

Sorbets, unlike ice creams, have no added dairy or non-dairy fat and are basically made from fruit, fruit pulp and/or juice and sugar, and can be stabilized with egg white, pectin or other gum stabilizers (Goff and Hartel 2013). It is considered a low-calorie product and due to their high-water content, it is a very light and refreshing dessert, consumed mainly in the summer months. In addition, it is suitable for vegans, vegetarians and those who suffer from allergies or intolerance to the ingredients in milk-based ice cream (Palka and Skotnicka 2022; Petkova et al. 2022).

In response to new health trends among consumers, the market has increasingly focused on developing new value-added products that offer health benefits. Sorbet, already considered as a lower-calorie and healthier product, is being studied as a food matrix for incorporating bioactive compounds (Williams et al. 2023). Research includes sugar and fat reduction through the addition of inulin, *Spirulina platensis* or phycocyanin extracts in ice creams (Da Silva Faresin et al. 2022), as well as the use of different fructans sources (Topolska et al. 2017), jujube fruit powder (*Zizyphus jujuba*), stevia leaf powder (*Stevia rebaudiana*) (Petkova et al. 2022) and amaranth proteins in fruit sorbet

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formulations (Malgor et al. 2020). These ingredients improved the technological characteristics of such products including the melting resistance and their stability.

Fruit consumption is often associated with a healthy lifestyle, as fruits are rich in bioactive compounds such as vitamins and phenolics, which have antioxidant and anti-inflammatory properties (Desmiaty et al. 2024). These compounds can reduce the risk of chronic and degenerative diseases (Majdan and Bobrowska-Korczak 2022). Among fruits, citrus fruits such as oranges (*Citrus Sinensis*) and acerola (*Malpighia emarginata*) stand out for their high vitamin content, especially vitamin C, which consists of ascorbic and dehydroascorbic acids and is recognized as a powerful polar antioxidant (Borges et al. 2022). Besides fruits, medicinal plants are also source of phenolic compounds, which are beneficial for health and food preservation (Nxumalo et al. 2023).

Dysphania ambrosioides L., commonly known as epazote, is a plant widely used in traditional medicine to treat various diseases such as flu, respiratory issues and gastrointestinal disorders. It contains a variety of bioactive compounds, mainly terpenes and phenolics, which exhibit pharmacological activity. Its use in food is limited to certain cultures, such as in Mexico, where it is used as a condiment (Kandsi et al. 2024). In terms of food applications, few studies have been carried out, with most focusing on its role in meat products as a natural antioxidant to prevent or reduce lipid oxidation (Villalobos-Delgado et al. 2017, 2020).

Given that ice cream is often used in hospital diets due to its nutritious content (Deosarkar et al. 2016), this study aimed to evaluate the effects of adding aqueous epazote extract at different concentrations to an orange-acerola sorbet. The study focused on selected technological and physicochemical parameters, including color, phenolic compounds, volatile compounds, ascorbic acid content, and sensory acceptance.

Materials and methods

Materials

The ingredients used to formulate the sorbet included: low-sugar fruit base for edible ice creams (Selecta Equilibrium) and orange and acerola flavoring, generously supplied by Duas Rodas Indústria. Sugar was purchased from a local market. The *D. ambrosiodes* leaves, used to produce the extract were collected from the Edem Space (16°35'42.5"S, 49°16'38.2"W) at the Agronomy School of the Federal University of Goiás (UFG), Brazil.

Preparation of extract

Leaves were collected at different development stages, selected, washed under running water, and sanitized in a 150-ppm sodium hypochlorite solution for 15 min. The leaves were dried in a forced-air oven (TE-394/3, Tecnal, São Paulo, Brazil) at 30 ± 2 °C for 18 hours or until they reached approximately 10% moisture content. The leaves were then ground into a powder using a knife mill and sieved through 35 mesh (0.50 mm) sieve, following a methodology adapted from Reyes-Becerril et al. 2019). The samples were vacuum-packed in aluminized containers and stored at room temperature for up to three months.

The extract was prepared according to the method adapted from Villalobos-Delgado et al. (2017). *D. ambrosioides* (DA) powder was mixed with drinking water in a 10:100 (m/v) ratio and kept under agitation at 120 rpm in a refrigerated incubator (TE-421, Tecnal, Piracicaba, Brazil) at room temperature (28 °C) for 1.5 hours. The mixture was filtered through qualitative filter paper, and the residue was extracted again under the same conditions. In the end, the filtrate was topped up with drinking water to a final volume of 100 mL, obtaining an extract with a concentration of 0.03 g/mL. The extract was stored in an amber bottle in a freezer (-18 °C) until use.

Preparation of sorbets

The sorbet formulations were prepared at the Food Engineering Processing Laboratory (UFG). Four sorbet formulations (0.4%, 0.8%, 1.6% and 3.3% p/v extracts) and a control (0% extract) were created (Table 1).

Table 1. Formulations of sorbets with different concentrations of DA extract.

Treatment	Water (g)	Sugar (g)	Base (g)	Extract (g)	Flavoring (g)
0%	1000.0	150	100	0	24
0.4%	995.7	150	100	4.3	24
0.8%	991.4	150	100	8.6	24
1.6%	983.2	150	100	16.8	24
3.3%	966.4	150	100	33.6	24

The mixtures were homogenized using a blender and poured into a Breville Express ice cream maker (Tramontina, 69170/012, China), on the "sorbet" setting, for the production and freezing steps. which the whole process resulted in a preparation time of 40–50 minutes. Afterwards, the sorbet mixture was transferred into plastic containers and hardened at -18 °C for 48 h to shape the final product, according to Jing et al. (2022) method.

Characterization of sorbets

Once hardened at -18 °C for 48 hours, the sorbets were analyzed for overrun, melting rate and behavior, color, pH and acidity.

Overrun, melting rate and melting behavior

Air incorporation (overrun) was measured according to Sangteerakij et al. (2022) method, with modifications.

First, the sorbet mixture was weighed in a plastic container, and the weight of the sorbet mixture was recorded. After 48 hours, the frozen sorbet was weighed in the same container to calculate air incorporation according to equation 1.

$$Overrun = \frac{\text{weigh of sorbet mix} - \text{weigh of sorbet}}{\text{weigh of sorbet}} \times 100 \quad (1)$$

The melting rate was determined according to the method adapted from Sangteerakij et al. (2022) and Singo and Beswa (2019). About 30 grams of sorbet were placed on a wire mesh which drained into a beaker, weighing the amount of sample that dripped over a period of 50 minutes. The mass of the melted sorbet was recorded every 5 minutes at 26 ± 2 °C to track the kinetics of the melting process. The recorded data was used to determine the melting rate (g/min).

The melting behavior was assessed through image analysis using a smartphone camera (iPhone X, Apple Inc., USA). Photographs were taken at fixed intervals of 10 minutes under ambient conditions (26 ± 2 °C), following an adapted method (Sangteerakij et al. 2022).

Color analysis

Color was analyzed directly in the container to measure CieLab parameters (L*, a* and b*) using a Minolta Baking Meter portable colorimeter (BC-10, Ramsey, Japan) in which L* represents luminosity (L*= 0 for black and L*= 100 for white), while a* and b* define chromaticity (+a* for red and -a* for green, +b* for yellow and -b* for blue), according to Singo and Beswa (2019). The data were converted to chroma (C*) and hue angle (H°) according to equations 2 and 3, and the color difference between the standard (SC) and the formulations with extract (SE) was calculated using equation 4 (Minolta 2007).

$$C^* = \sqrt{a^{*2} + b^{*2}} \quad (2)$$

$$hue^\circ = \arctan b/a \quad (3)$$

$$\Delta E = \sqrt{L^*_{sc} - L^{*2}_{se} + a^*_{sc} - a^{*2}_{se} + b^*_{sc} - b^{*2}_{se}} \quad (4)$$

Total soluble solids, pH and titratable acidity

The pH was assessed directly from the sample using a pre-calibrated portable potentiometer (Hanna, H19816, São Paulo, Brazil) with an accuracy of 0.002 pH units. Total soluble solids and titratable acidity were determined using AOAC methodologies. For total solids, a benchtop digital refractometer (Instrutherm, RTD-95, São Paulo, Brazil) was used according to method 932.12 (AOAC 1995). Titratable acidity was determined using the potentiometric method with 0.1 M NaOH solution until a pH of 8.3 was reached, following method 942.15 (AOAC 2000). Titratable acidity was expressed as g of citric acid/100 g of product.

Determination of total phenolic content (TPC)

The TPC was determined using the methodology adapted from Villalobos-Delgado et al. (2017). Samples were previously centrifuged at 10,000 rpm for 10 min, and a 50 µL aliquot of each sample was added to 3 mL of milli-Q water and 250 µL of Folin-Ciocalteu reagent (1N). After 5 minutes, 750 µL of 20% Na CO solution and 950 µL of milli-Q water were added. The mixture was homogenized and left to stand for 60 minutes. The absorbance was measured at 760 nm using a spectrophotometer (Shimadzu, UV-1800, Japan), and the concentration was determined using a gallic acid calibration curve (0 and 1000 µg/mL). Results were expressed as mg of gallic acid per 100 g of product.

Profile of volatile organic compounds

Volatile compounds were extracted using headspace (HS) at 80 °C, 250 rpm, for 30 min in an AOC-6000 Plus automatic sampler. They were identified by Shimadzu Nexis GC-MS (GC2030, Kyoto, Japan) coupled to a QP2020 NX mass spectrometer (electron impact). The analysis conditions were: injector, interface and ion source temperature of 250 °C, SH-Stabilwax-ms column (30 m × 250 µm, 0.25 µm), electron ionization applied at 70 eV and mass acquisition range from 40 to 400 m/z with a scan time of 150 ms. Data were compared with reference compounds from the NIST 17 library. The oven temperature was maintained at 40 °C for 5 minutes, increased to 160 °C at a rate of 5 °C/min, and finally increased at a rate of 10 °C/min up to 250 °C, maintained for 15 minutes. The total analysis time was 53 minutes, following a methodology adapted from Alves et al. (2023). The injection volume was 1000 µL in 1:10 split mode, and helium was used as the carrier gas at a constant flow rate of 0.94 mL/ min and a linear velocity of 35.0 cm/s. For compound identification, the linear retention index (LRI) of each compound was compared with the LRI standards of the C10–C40 alkanes.

Determination of ascorbic acid by liquid chromatography

Samples were centrifuged at 10,000 rpm for 10 min and filtered through a 0.45 µm membrane. Vitamin C was quantified using LC-20 AT (Shimadzu, Japan) liquid chromatography system with an SPD-20A UV/Vis detector set at 242 nm. The column used was a Shim-pack VP-ODS (4.6 × 150 mm, 5 µm) and the mobile phase consisted of a 25 mmol.L^{-1} phosphate buffer 25 at pH 5.7 + 5 mmol.L^{-1} sodium hexasulfonate (A), acetonitrile (B) and methanol (C). The analysis was carried out under a gradient regime, with a flow rate of 0.8 mL.min-^{1}, an injection volume of 5 $^{-1}$ µL and an oven temperature of 40 °C, following a methodology adapted from Abe-Matsumoto et al. (2016). Vitamin C concentration was calculated using the calibration

curve for the ascorbic acid (AA) standard, and AA identification was carried out based on the retention time and the UV absorption spectrum of the AA standard.

Sensory and microbiological analyses

Sensory analysis of the sorbets was conducted in the Sensory Analysis laboratory of the Food Engineering Department (UFG) using a 9-point hedonic scale (9 = extremely liked, 5 = neither liked nor disliked and 1 = extremely disliked). The attributes evaluated included appearance, color, aroma, flavor, texture and overall acceptance. Purchase intent was assessed using a 5-point scale (1 = certainly would not buy; 5 = certainly would buy). All the formulations were coded and given simultaneously in plastic cups to 110 untrained tasters (consumers), comprising adults aged between 19 and 64, 59% were women and 41% men. The research project was approved by the UFG Research Ethics Committee (n° CAAE 70254723.7.0000.508).

Microbiological analyses followed ISO standards for edible ice cream category. Enterobacteriaceae were analyzed in accordance with ISO (2017), and *Salmonella* according to ISO (2020).

Statistical analysis

Data were expressed as mean ± standard deviation. Statistical significance was determined using one-way analysis of variance (ANOVA) and treatments compared using Tukey's test at a 5% significance level, performed using Statistic 14 software (TIBCO Software Inc 2020) test.

Results and discussion

Physicochemical characterization of sorbets

Important quality parameters of sorbets were studied in order to evaluate their matrices (Petkova et al. 2022). The results for pH, acidity and total soluble solids are shown in Table 2.

All sorbet formulations had a low pH, indicating an acidic product due to the inclusion of orange and acerola flavoring, both of which are citrus fruits. However, significant changes in pH and acidity values were observed in the sorbets containing the highest concentrations (1.6% and 3.3%) of extracts compared to the control – sorbet without extract (0%). Such variations may be attributed to the pH value of the extract, which had a relatively basic nature (~7.5) in preliminary tests. Although changes in pH (0.03–0.07 units) and acidity (0.02–0.04 g/100 g) were significant, they were not substantial enough to impact the practical perspective and the sensory attributes.

Table 2. Effect of different concentrations of DA extract on selected chemical parameters.

Treatment	pH	Titratable acidity (g of citric acid/100 g)	Soluble solids
0%	2.42 ± 0.03^{c}	0.57 ± 0.02^{a}	20.01 ± 1.12^{a}
0.4%	2.44 ± 0.03^{bc}	0.57 ± 0.01^{a}	19.97 ± 2.14^{a}
0.8%	2.45 ± 0.01^{b}	0.58 ± 0.01^{a}	18.86 ± 0.65^{a}
1.6%	2.46 ± 0.02^{ab}	0.53 ± 0.01^{b}	19.20 ± 1.52^{a}
3.3%	2.49 ± 0.02^{a}	0.55 ± 0.01^{b}	19.94 ± 0.60^{a}

Different letters in the same column indicate statistically significant differences ($p < 0.05$) by Tukey's test.

The pH values were found lower while the acidity was found higher than those observed by Petkova et al. (2022), when evaluating peach sorbet with *Zizyphus jujuba* and *Stevia rebaudiana* powder. Patil et al. (2017) attributed pH increases in ice creams (prepared with buffalo milk) with herbal and crystal menthols to phenolic substances in mint (*Mentha arvensis*). Da Silva Faresin et al. (2022) reported that the increase in pH values of ice cream containing inulin, *Spirulina platensis* or phycocyanin extracts was due to the addition of milk and other sources of soluble solids.

Regarding the total soluble solids content, the addition of the extract in sorbet formulations had no significant influence. The formulation used in this study resulted in lower values than those reported by Petkova et al. (2022) for peach sorbets with added stevia (*Stevia rebaudiana*) and jujube (*Zizyphus jujuba*) powder, and by Sangteerakij et al. (2022) for mulberry fruit sorbets (*Morus alba* L.), which used sugar proportions of 15 to 16%, similar to this study. The total solids content depends on the ingredients used, with sugar being a key factor, especially in sorbets (Rahim and Sarbon 2019).

In all the color parameters evaluated (Table 3), chroma and b* values showed no significant differences between the formulations. Both a* and b* values showed a tendency towards red and yellow chromaticity, similar to the findings of Petkova et al. (2022) in peach sorbets incorporated with added stevia and jujube powder. However, there were differences in lightness (L*), with the highest extract concentration (3.3%), and in redness (a*) and hue angle in the sorbets with 1.6%. These differences suggest an increase in both lightness and a* values, along with a decrease in the hue angle.

Table 3. Effect of different concentration of DA extract on the color values of sorbets.

Trat.	L*	a*	b*	C	Hue	ΔE
0%	62.78 ± 2.39^{b}	1.23 ± 0.40^{b}	40.18 ± 6.84^{a}	40.20 ± 6.48^{a}	88.14 ± 0.83^{a}	-
0.4%	62.36 ± 2.78^{b}	1.21 ± 0.40^{b}	40.58 ± 2.15^{a}	40.60 ± 2.15^{a}	88.29 ± 0.56^{a}	3.4 ± 0.49^{a}
0.8%	62.60 ± 2.82^{b}	1.10 ± 0.28^{b}	40.23 ± 1.65^{a}	40.25 ± 1.65^{a}	88.43 ± 0.39^{a}	3.5 ± 0.57^{a}
1.6%	64.12 ± 2.15^{ab}	1.69 ± 0.55^{a}	41.19 ± 2.92^{a}	41.23 ± 2.91^{a}	87.63 ± 0.86^{b}	3.6 ± 0.73^{a}
3.3%	64.49 ± 2.86^{a}	1.92 ± 0.35^{a}	41.76 ± 1.85^{a}	41.80 ± 1.84^{a}	87.36 ± 0.50^{b}	3.6 ± 0.63^{a}

(-) no data. Different letters in the same column indicate statistically significant differences ($p < 0.05$) by Tukey's test.

The addition of the extract at these concentrations made the product lighter and slightly less yellow, likely due to the colored pigments in the extract (Singo and Beswa 2019).

According Krahl et al. (2024), the aerating process can also contribute to a whitening effect. The coloring extract (light greenish brown), combined with the aerating process, explains the whitening effect observed, as indicated by the increase in L* value in the sorbet with 3.3% extract. The increase in a* value is also due to the extract's brownish color. The color difference between the sorbets did not show a statistical difference, indicating that the colors of the sorbet formulations with extract were similar to the color of the control sorbet. This was more noticeable in the sorbets with higher concentrations, where the ΔE was between 3.5 and 5, showing a clear difference in color (Mokrzycki and Tatol 2011).

Overrun (air incorporation) and melting rate showed no significant difference between the formulations (Table 4), indicating that the addition of the extract did not impact these quality parameters. While overrun values tended to decrease with higher extract concentrations, no significant differences were observed between the control and extract formulations. Generally, air incorporation typically ranges from 20% or less due to the lack of protein, which limits the stability of the air cells (Goff and Hartel 2013) in the sorbets studied here, as they have no milk added. Without milk protein, less air is incorporated into the sorbet, resulting in a lower overrun value (Sangteerakij et al. 2022). The average overrun for the products ranged from 18.59% to 22.10%, which is the expected range for sorbets and similar to the values reported by Palka and Skotnicka (2022) for avocado (18.67%) and mango (19.67%) sorbets with 5% inulin added.

The melting rate is influenced by air incorporation, in which a low overrun value is associated with a low melting rate (Singo and Beswa 2019; Petkova et al. 2022). In this study, the melting rate ranged from 1.05 to 1.15 g/min, values close to those found by Singo and Beswa (2019) for ice cream with 5% sour caruru extract (*Hibiscus sabdariffa*), which had a melting rate of 1.3 g/min. The melting rates observed in this study reflect the melting behavior of the samples, which showed similar kinetics curves, with a time of 45 min and complete melting behavior at 50 minutes (Figs 1, 2). The time of the kinetics curves is close to that reported by Malgor et al. (2020) for lemon sorbet made with amaranth protein (*Amaranthus hypochondriacus*), which melted in 43.1 min.

Table 4. Effect of different concentrations of DA extract in overrun values and melting rate of sorbets.0

Treatment	Overrun	Meting rate (g/min)
0%	20.62 ± 2.31[a]	1.11 ± 0.09[a]
0.4%	22.10 ± 2.57[a]	1.14 ± 0.16[a]
0.8%	19.57 ± 2.44[a]	1.05 ± 0.13[a]
1.6%	19.90 ± 2.99[a]	1.20 ± 0.13[a]
3.3%	18.59 ± 2.51[a]	1.11 ± 0.12[a]

Different letters in the same column indicate statistically significant differences ($p < 0.05$) by Tukey's test.

Fig. 2 shows the melting behavior of around 20 grams of each sorbet, placed in a porcelain container at an ambient temperature of 26 ± 2 °C, over a total test of 50 minutes. The results indicated no significant correlation between extract concentrations and melting time ($p > 0.05$). In contrast, other studies have found longer melting times, ranging from 60 to 90 min, using larger sample sizes of 100 grams (Tsai et al. 2020; Petkova et al. 2022). Melting resistance is an important factor in consumer experience when consuming ice cream. A product that melts too quickly can lead to an uncomfortable and undesirable situation for the consumer (Goff and Hartel 2013; Petkova et al. 2022).

Bioactive characteristics of sorbets

The total phenolic content (TPC) analysis revealed that the addition of the extract at the highest concentration (3.3%) increased the TPC from 48.52 mg of gallic acid

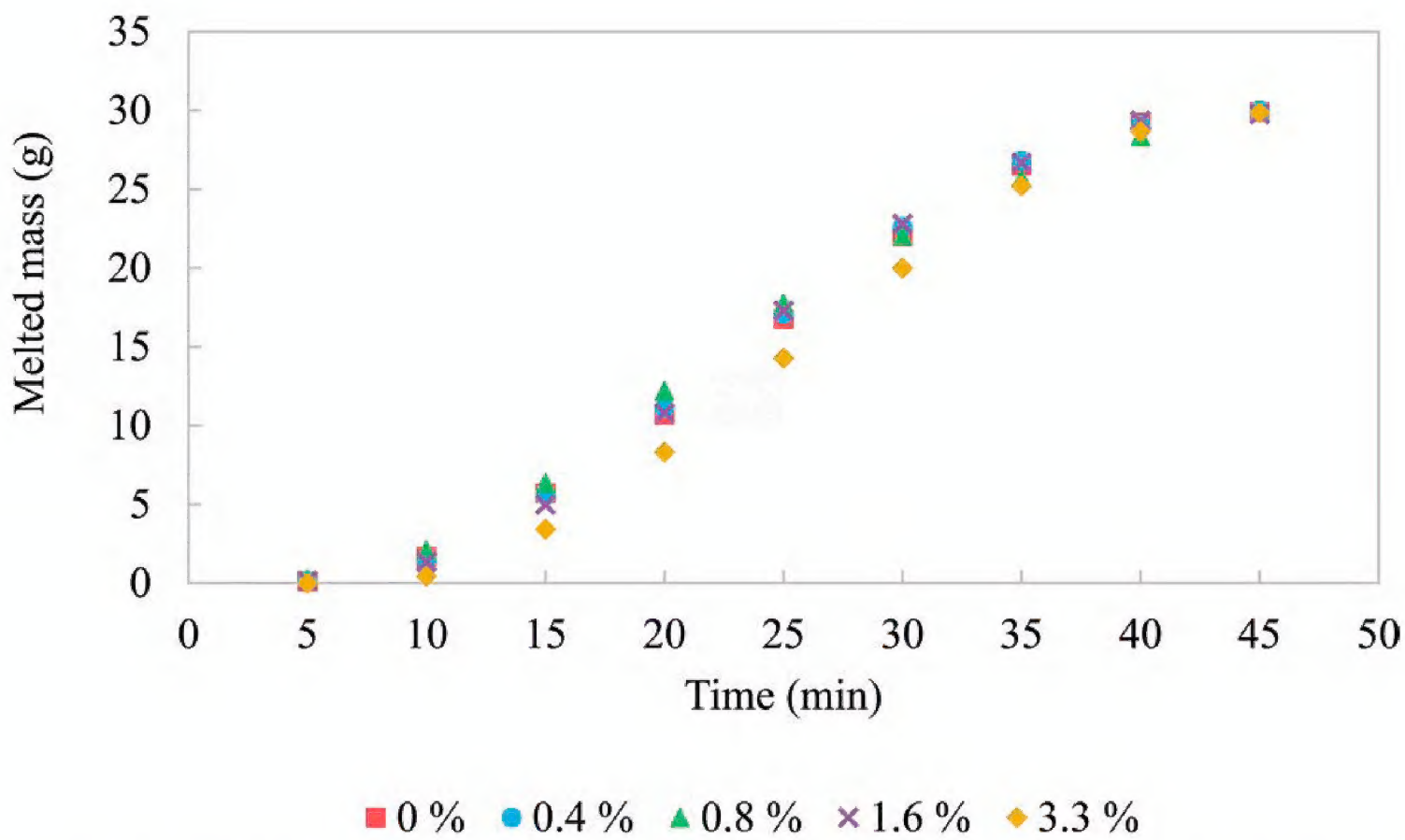

Figure 1. Melting kinetics of control sorbets and sorbets added with different concentrations of extract.

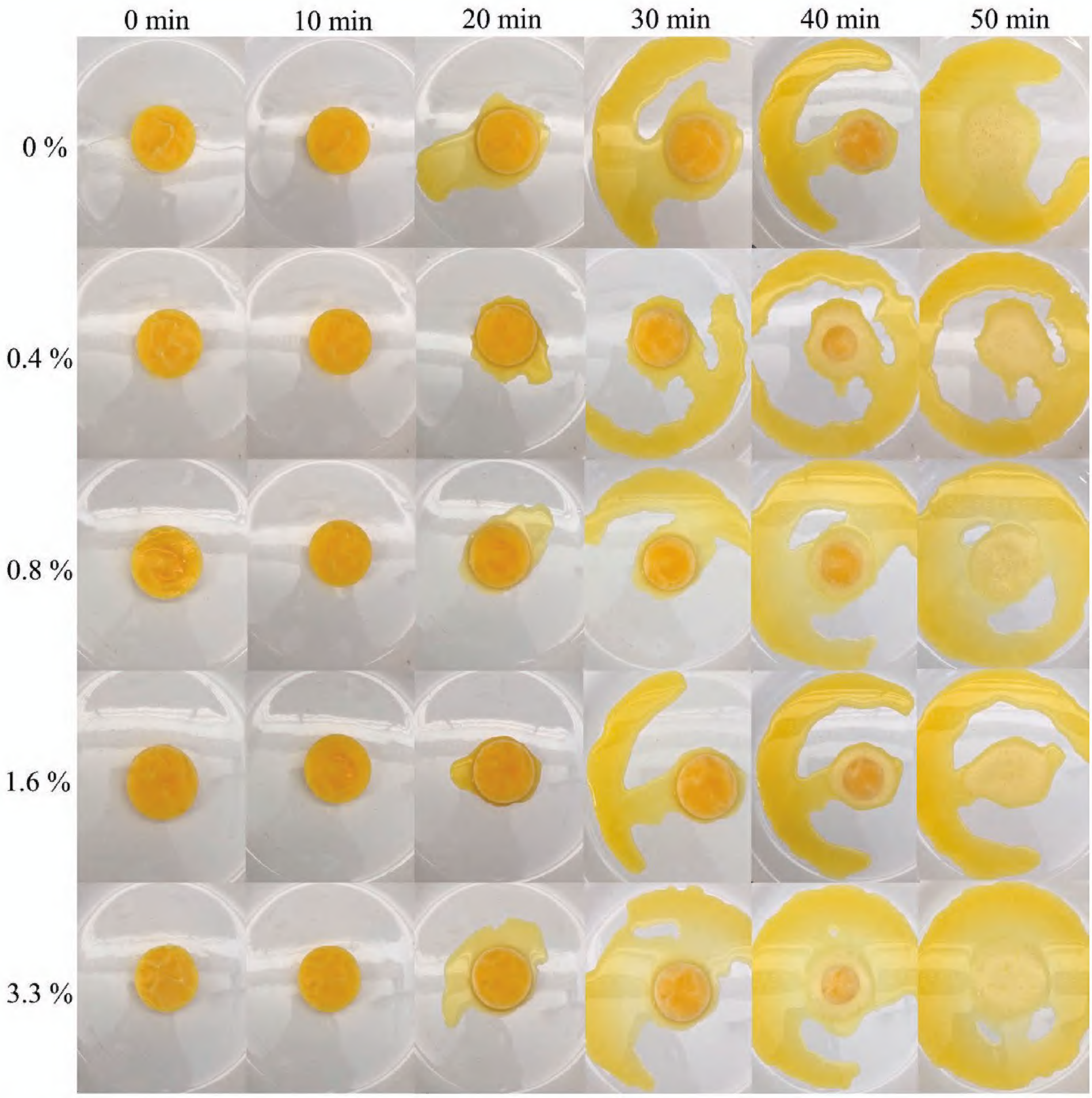

Figure 2. Photos taken during the melting behavior of sorbet formulations at different times.

equivalents (GA)/ 100 g (0%) to 55.48 mg GA/100 g (3.3%), a1.14-fold increase ($p < 0.05$) (Fig. 3). These values are comparable to those found by Dos Santos Cruxen et al. (2017) in sorbets with 30% butiá pulp (*Butia odorata*), which had 48.9 mg/100 g. A 10% increase in pulp concentration resulted in a 1.23-fold rise in TPC (60.2 mg/100 g). In contrast, Petkova et al. (2022) evaluated the addition of jujube powder to peach sorbet (Palka and Skotnicka 2022) the addition of inulin to avocado and mango sorbets and they identified a reduction the TPC of the products.

The extract and flavoring content were also analyzed and showed no statistical difference, with values of 33.54 ± 2.1 mg/100 g and 35.06 mg/100 g, respectively. Other ingredients used, such as the sorbet base and sugar, may have contributed to the increase in TPC content. The higher TPC found in sorbets with greater extract concentration

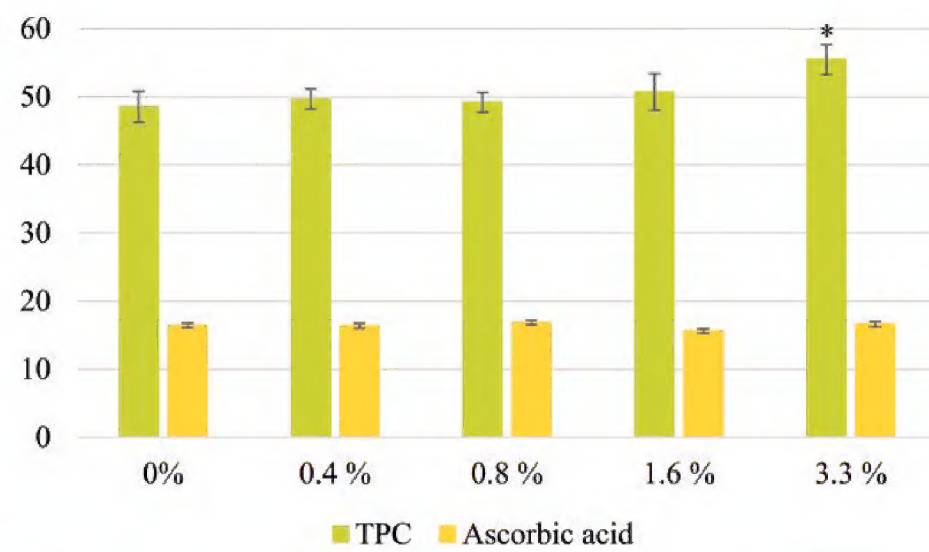

Figure 3. Total phenolic content (mg of gallic acid/100 g) and ascorbic acid (mg/ 100 g) content of sorbet formulations. * Indicate statistically significant differences ($p < 0.05$) by Tukey's test.

suggests the influence of specific plant compounds, such as o-cymene, whose percentage increased as the extract concentration rose, based on the volatile compound analysis.

Unlike TPC, the vitamin C content, quantified as ascorbic acid (AA), showed a reduction during processing and/or freezing, decreasing from 34.25 ± 1.08 mg/100 g (flavoring) to 15.60 ± 0.31 to 16.61 ± 0.39 mg/100 g (sorbet formulations), with no statistical difference between formulations ($p < 0.05$). The extract itself showed a low AA content (4.13 ± 0.06 mg/100 g). Fig. 3 shows that there is no consistent trend in AA values decreasing with increasing extract concentration, suggesting the reduction in AA was due to processing and freezing.

The same behavior was observed by Freire et al. (2013), who evaluated the ascorbic acid content in fresh acerola (1457.69 mg/100 g) and its frozen pulp (778.10 mg/100 g). They identified a reduction in AA content as a result of freezing and storage, considering the susceptibility of ascorbic acid to degradation. The loss of vitamin C may have been a result of the freezing process (time and temperature) as well as the storage conditions, such as temperature and its fluctuation, and the duration of storage, as the products were stored in a domestic freezer (Palka and Skotnicka 2022). Thawing the sample could also have degraded the ascorbic acid (Hernández et al. 2006).

Although the flavoring consisted of orange and acerola, both fruits considered rich in vitamin C-especially acerola-the sorbet did not show significant ascorbic acid content. This reduction may have resulted from processing and freezing, as well as the amount of flavoring used in the formulation (24 g/L). However, sorbets were prepared according to the recommended dosage from technical specification. Depending on the products' acidity, sorbets may not be well accepted by the consumer (Hipólito et al. 2016).

Table 5. Volatile compounds of sorbets with different concentrations of DA extract.

Compound	LRI_L	LRI_C	Area (%)				
			0%	0.4%	0.8%	1.6%	3.3%
Etanol	-	-	1.71	2.03	2.91	2.56	8.28
β-mircene	1178	1173	1.51	1.47	1.46	1.45	1.40
d-limonene	1193	1186	90.74	89.65	88.62	87.43	81.81
γ-terpinene	1219	1230	1.77	1.79	1.68	1.65	1.51
o-cimene	1234	1243	0.41	0.56	1.00	1.40	2.42
o-cimenene	1420	1429	-	-	-	0.65	1.10
α-terpinyl acetate	1721	1751	0.50	0.54	0.63	0.69	0.76
Tumerone	2295	2245	0.36	0.38	0.33	0.38	0.24
aR-Turmerone	-	-	1.82	2.39	1.83	2.07	1.67

(-) not detected.

Among the volatile compounds identified in the sorbets, the terpenes β-myrcene and d-limonene, originating from the orange and acerola powder (Cappato et al. 2018; Xie et al. 2023), were present in all formulations. A reduction in d-limonene was observed, which consequently increased the percentage of o-cymene, an antioxidant compound found in *Dysphania ambrosioides* essential oils (Kandsi et al. 2022). This increase in o-cymene may be attributed to the concentration of the extract, where, part of the water used in the sorbets was replaced by the extract, even though the powder content remained constant. This substitution may have affected the percentage of d-limonene as well.

The compound o-cymenene (also known as o-Isopropenyltoluene), a secondary product of o-cymene, was identified only in the sorbets with 1.6 and 3.3% extract concentrations and is also known for its antioxidant activity (Bagińska et al. 2024). Another compound which had an increase in its percentage area was α-terpinyl acetate, probably due to the higher extract concentration.

Microbiological analysis and sensory acceptance

In order to guarantee the safety of sorbets for consumption, microbiological analysis was carried out on all formulations, which met the required criteria for total Enterobacteriaceae count and *Salmonella* spp detection (Table 6), as established by Normative Instruction no. 161 (Anvisa 2022) for edible ice creams.

Table 6. Microbiological analysis of sorbets with different concentrations of DA extract.

Treatment	Enterobacteriaceae (CFU/g)	*Salmonella* ssp (/25 g)
0%	<10	Not Detected
0.4%	<10	Not Detected
0.8%	<10	Not Detected
1.6%	<10	Not Detected
3.3%	<10	Not Detected
Limit level	100	Not Detected

The acceptability test used a 9-point hedonic scale and the results for the sorbets presented as average scores in a radar graph (Fig. 4). The average scores for the attributes ranged from 8 (I liked it very much) to 7 (I liked it moderately), indicating that the sorbet formulations with extract were well accepted by the participants. Unlike Hipólito et al. (2016), who reported low acceptability for citrus-based sorbets-including orange-the citrus sorbets in this study were well accepted.

The addition of the extract did not affect the appearance, aroma or texture, but did influence taste and overall assessment. The sample with the highest extract concentration (3.3%) had a significantly different taste and overall assessment ($p < 0.05$), with average scores of 6.7 ± 2.1 for taste and 7.0 ± 1.6 for overall assessment. This suggests the consumer perception of *D. ambrosioides* flavor that is known for its bitter taste (Pinela et al. 2017), which likely influenced the taste perception. Similarly, Petkova et al. (2022) found that adding jujuba powder to sorbets changed the taste, and the use of stevia in place of sugar also contributed to bitterness.

The aroma received the highest score of 5, indicating "neither liked nor disliked", and was barely perceived by the participants. Although *D. ambrosioides* has

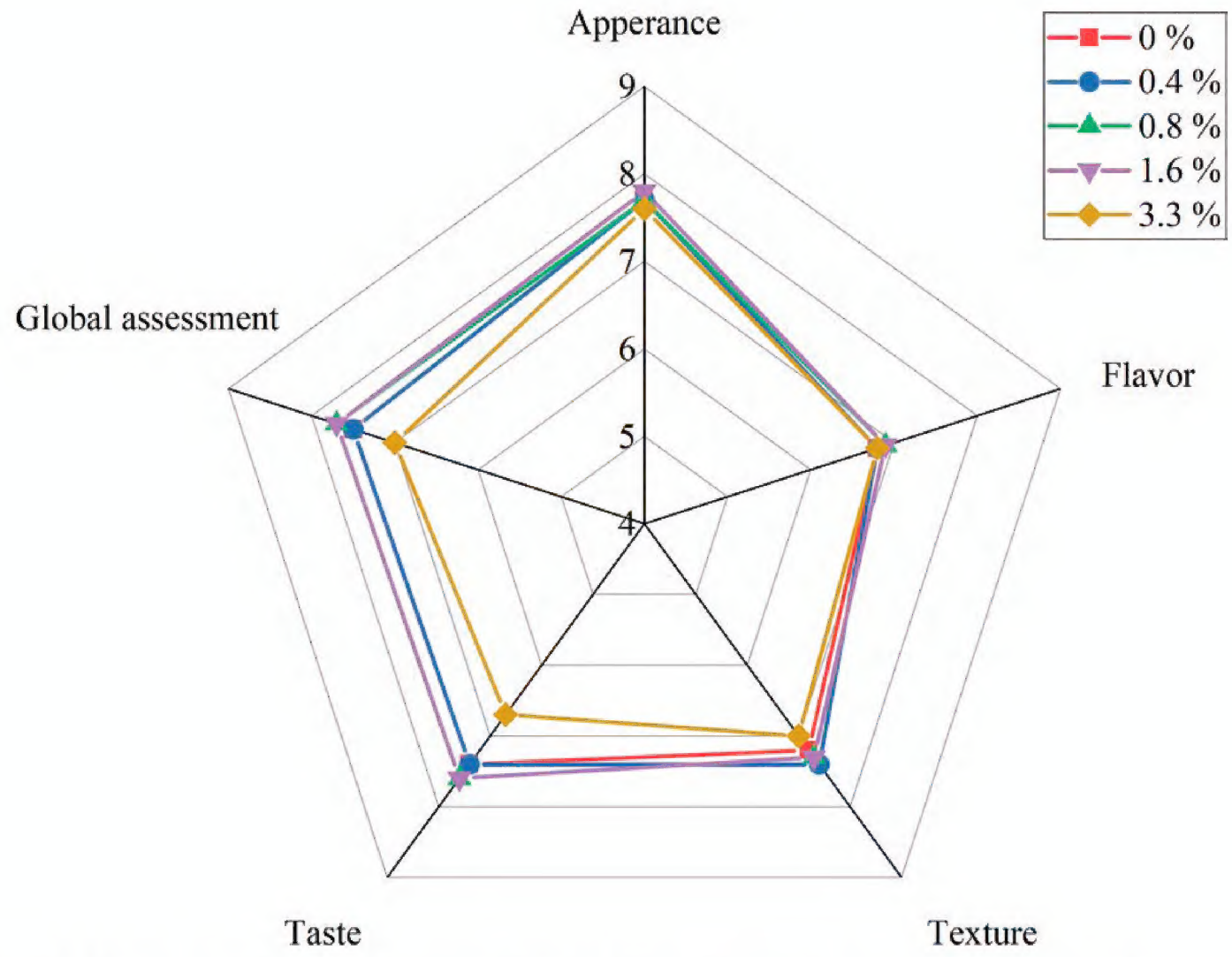

Figure 4. Radar chart showing average scores for sensory evaluation of sorbets formulations.

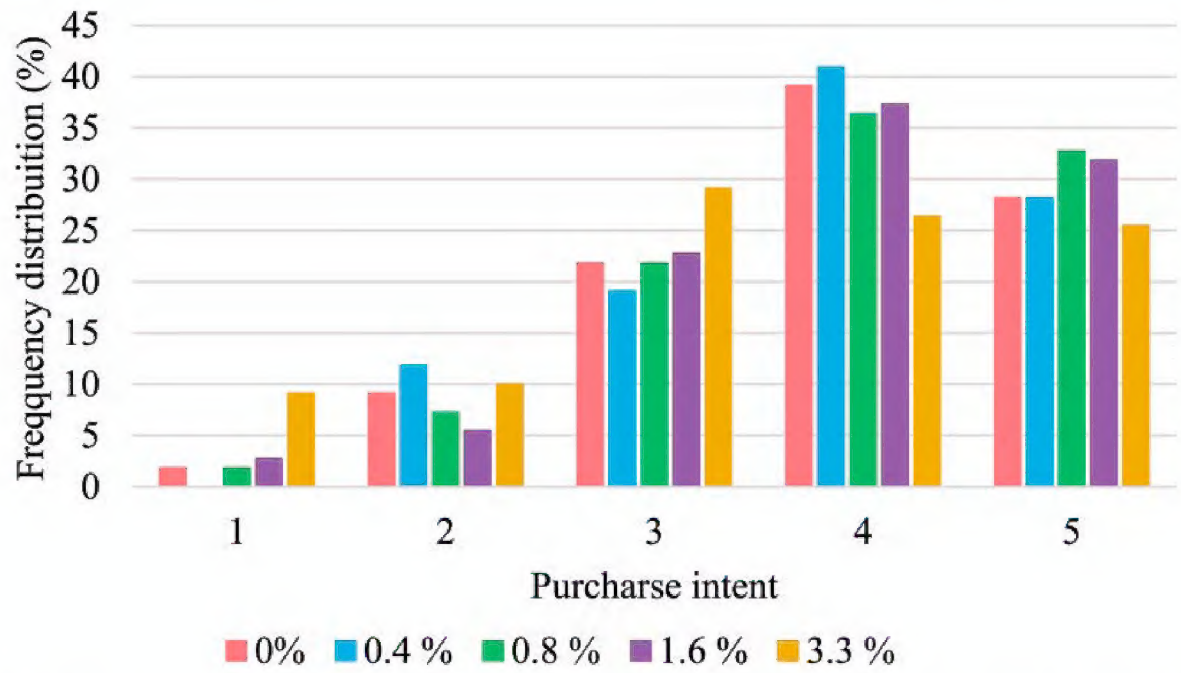

Figure 5. Frequency distribution (%) of the purchase intent for sensory evaluations of sorbet formulations.

a characteristic aroma, it was likely masked by the fruit powder and the processing methods used, making it less evident in the sensory evaluation. The texture was evaluated with comments such as "melting fast", which may have been influenced by the uncontrolled ambient temperature during the test. However, since sorbets are water-based products and the formulations presented a low melting rate, this could justify the faster melting observed during analysis (Palka and Skotnicka 2022).

Regarding purchase intent, participants indicated higher interest in the intermediate extract formulations (0.4, 0.8 and 1.6%) when compared to the control, with 69% expressing they "certainly would buy" or "probably would buy" the sorbets with extract, versus 67% for the control sorbet. The sorbet with the highest extract concentration (3.3%) also showed considerable purchase intent, with over 50% of participants expressing interest (Fig. 5).

Conclusion

The addition of aqueous *Dysphania ambrosioides* leaf extract at higher concentrations (1.6 and 3.3%) in orange-acerola sorbet influenced pH, acidity and color parameters but had no impact on technological parameters such as overrun and melting rate. Furthermore, these formulations exhibited a concentration-dependent increase in the percentage of the peak area of the o-cymene compound, which contributed to a higher total phenolic content, particularly in the 3.3% formulation. However, the ascorbic acid content was unaffected by the extract, though the freezing and storage process affect its content, even in the formulations with the highest concentrations.

The addition of *D. ambrosioides* extract at the highest concentration (3.3%) could offer a sorbet with a higher content of phenolic compounds, including o-cymene,

known for its health benefits-without compromising quality parameters, and it was well accepted by consumers. Futures studies could further explore its functional properties and potential benefits for consumer well-being.

Author contributions

Ishizawa and Machado designed research concept, methodology and conducted experiments. Da Silva, Castiglione and Pereira assisted in the methodology. Ishizawa and Colivet analyzed the data. Ishizawa wrote the original manuscript. Colivet and De Oliveira reviewed and edited the manuscript. De Oliveira supervised the project and manuscript. All authors contributed to the manuscript.

Conflicts of interest

The authors have declared that no competing interests exist.

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